Internal Wave Parameters Inferred from ADCP Records

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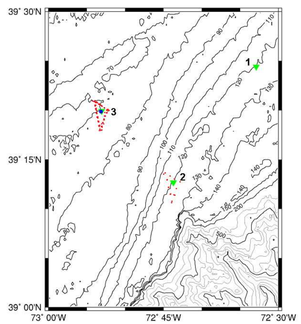
Abstract

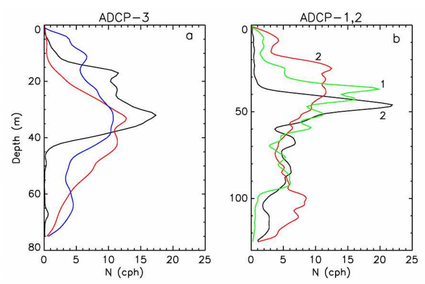
A method for extracting internal wave characteristics from time series of current velocity profiles, measured by moored acoustic Doppler current profilers (ADCPs) is described. Horizontal and vertical velocity components at each depth level are band-pass filtered to isolate high-frequency internal waves (periods between 2 h and 12 min). Filtered data are decomposed into depth-time empirical orthogonal function (EOF) modes which compare quite favorably with dynamical internal wave modes based on local buoyancy frequency profiles. Vertical displacement is derived by temporally integrating vertical velocity. Modal flux series, formed by the product of displacement and horizontal velocity, are analyzed to determine amplitude and direction of internal wave packets. Results compare favorably with concurrent moored thermistor chain measurements. Examples of the vertical circulation associated with wave packets are presented. The generation of a synthetic time-dependent profile of sound speed, based on ADCP vertical displacement series, Is presented.

1



Locations of moored ADCPs (green triangles) and CTD sections (red dots).

2



Buoyancy Frequency (N) profiles at (a) ADCP-3: average of short, initial yoyo cast (black); average of profiles shown in Figure 1 (red); average of day-long yoyo cast during first week (blue); (b) ADCP-2: average of short, initial yoyo cast (black); average of profiles shown in Figure 1 (red); ADCP-1: (average of short, initial yoyo cast (green).

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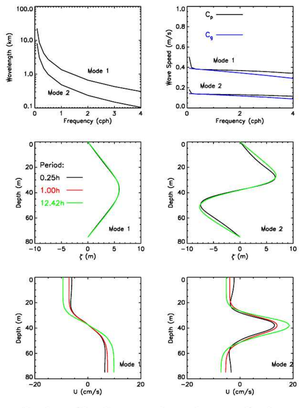

Dynamical vertical normal mode results based on the buoyancy frequency profile above (panel a, red curve): (a) wavelength, (b) phase (black) and group (blue) speed as functions of frequency; vertical structure for modes 1 and 2 for (c,d) vertical and (e,f) horizontal velocity. For example, W(z,t)=)=?D_j(z)F_j(t), j=1,nz.

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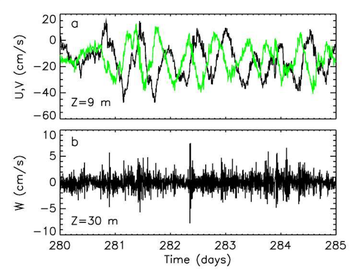

Five-day sample of current velocity components from ADCP-3: (a) eastward (U) and northward (V, green) at 9 m; (b) upward (W) at 30 m.

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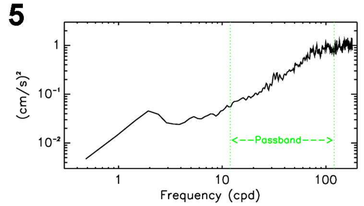

Variance-preserving autospectrum of vertical velocity (W) at depth 40 m from ADCP 3. The highest energy is found at periods of about 30 minutes and less. U, V, W are bandpass filtered between 2.0 and 0.2 h (geen vertical lines), and elevation is calculated: ζ (z,t)=?W(z,t) dt.

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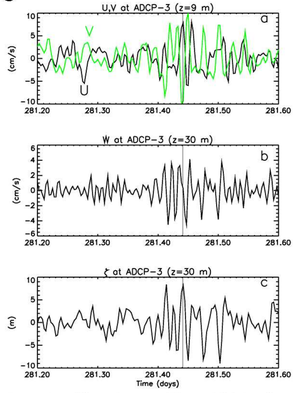
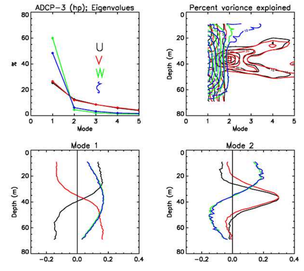


Sample of band-pass filtered (a) horizontal velocity (U, V (green)) at 9 m, (b) vertical velocity (W) at 30 m and (c) elevation (ζ) calculated from W at 30 m, for a selected 0.4 d period.

7

EOF expansions are made on U, V, W, ζ. For example, W(z,t)=?Z_j(z)E_j(t), j=1,nz, where the Z_j are orthonormal and the eigenfuctions of the covariance function for W.



Empirical orthogonal function results for ADCP-3: (a) eigenvalues (legend applies to all panels), (b) percent variance explained, (c,d) eigenfuctions for modes 1,2.

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Quantitative tests of the relevance of the theoretical results are vertical and temporal correlations of EOFs and fits (Kundu et al., 1975) to the dynamical profiles. That is:

r_{tk} = cor(E_k,F_k) and r_{zk} = cor(Z_k,D_k).

Correlations for modes 1 and 2 are generally high (> 0.80) for all 3 ADCPs. For mode 1, most are >0.90 and at ADCP-3 are ~0.99. Hence, in this case, EOFs provide an effective estimate of dynamical modal structure.

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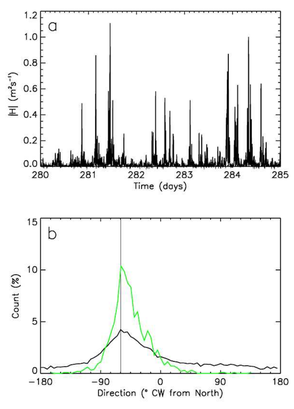
We define a flux vector $H_k(t)$= $\zeta_k(U_k,V_k)$ for EOF mode k,where (e.g.) for mode 1 U_k, V_k are taken near the surfaceand ζ_k is at the depth of the thermocline.



(a) Magnitude of H_1 (mode 1) at ADCP-3 for a 5 day period; (b) histogram of direction of H_1 for entire record and for magnitudes above 0.10 m^2s^{-1} (green). Mode 2 (not shown) has lower magnitude and less well-defined direction.

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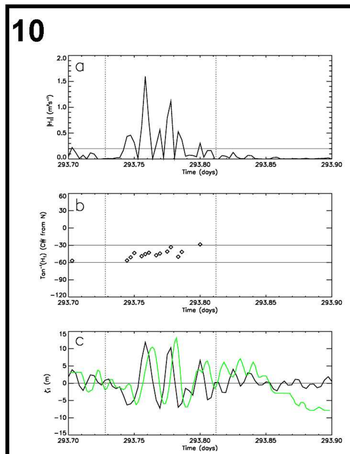

(a)Magnitude and (b) direction (for magnitude above 0.10 m^2s^{-1}) of H_1 and (c) ζ_1 and thermocline height (green) from moored chain data, for a 0.2 day period near the end of the ADCP-3 record.

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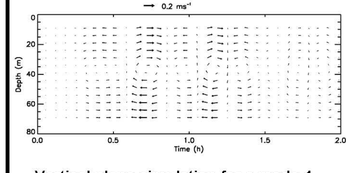
The vertical plane circulation associated with internal wave packets can be displayed by first rotating the horizontal coordinates so that the horizontal axis (x') points opposite to the direction of propagation (panel b, left). Then, a propagating feature can be represented by f(x'+ct), where c is the propagation speed. Circulation cells (at ADCP 3) depicted in the depth-time domain are hence consistently represented in the 2-hour segment below (indicated in the plots at left by vertical dotted lines).



Vertical plane circulation for a mode-1 internal wave packet at ADCP-3.

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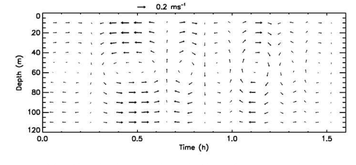
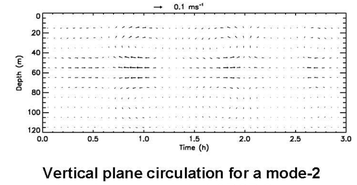
Similarly, for ADCP records at the other locations…



Vertical plane circulation for a mode-1 internal wave packet at ADCP-1.



Vertical plane circulation for a mode-2 internal wave packet at ADCP-2.

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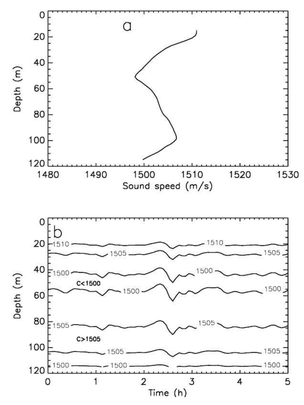
Given a mean (e.g.) sound speed profile, C_0(z), A synthetic time-varying profile can be generated Using ζ(z,t) derived from the ADCP record, That is: C(z,t)=C_0(z+ ζ(z,t)).



(a) Average sound speed profile at ADCP-2; based on the triangle of CTD stations shown in Figure 1. (b) Synthetic sound speed time section based on the profile in (a) and ζ_1 from ADCP-2. Five hours from day 283 are shown.